Taylor & Francis
Taylor & Francis Group

Philosophical Magazine Series 3

ISSN: 1941-5966 (Print) 1941-5974 (Online) Journal homepage: http://www.tandfonline.com/loi/tphm14

XII. The effect of pressure in lowering the freezing-point of water experimentally demonstrated

Professor W. Thomson

To cite this article: Professor W. Thomson (1850) XII. The effect of pressure in lowering the freezing-point of water experimentally demonstrated , Philosophical Magazine Series 3, 37:248, 123-127, DOI: 10.1080/14786445008646566

To link to this article: http://dx.doi.org/10.1080/14786445008646566

Published online: 30 Apr 2009.

figures that it may almost be taken for granted that, as in this instance, when there is an exception in this particular, it is due to some subsequent change having taken place in one or other of the colours. In the case before us our first tracing was coloured with the verdigris-green: it was unsatisfactory; but on making a new tracing and colouring it according to our amended observations, it at once became harmonious in colour, and assumed an intelligible form, though all our colouring will not enable us to convey the idea of ruby-gemmed flowers like the substance used, the transparency of glass contributing much to the general effect.

XII. *The Effect of Pressure in Lowering the Freezing-Point of Water experimentally demonstrated.* By Professor W. Thomson, *Glasgow**.

On the 2nd of January 1849, a communication entitled "Theoretical Considerations on the Effect of Pressure in Lowering the Freezing-Point of Water, by James Thomson, Esq., of Glasgow," was laid before the Royal Society, and it has since been published in the Transactions, vol. xvi. part 5†. In that paper it was demonstrated that, if the fundamental axiom of Carnot's Theory of the Motive Power of Heat be admitted, it follows, as a rigorous consequence, that the temperature at which ice melts will be lowered by the application of pressure; and the extent of this effect due to a given amount of pressure was deduced by a reasoning analogous to that of Carnot from Regnault's experimental determination of the latent heat, and the pressure of saturated aqueous vapour at various temperatures differing very little from the ordinary freezing-point of water. Reducing to Fahrenheit's scale the final result of the paper, we find

$$t=n\times 0{\cdot}0135;$$

where t denotes the depression in the temperature of melting ice produced by the addition of n "atmospheres" (or n times the pressure due to 29·922 inches of mercury), to the ordinary pressure experienced from the atmosphere.

In this very remarkable speculation, an entirely novel physical phænomenon was *predicted* in anticipation of any direct experiments on the subject; and the actual observation of the phænomenon was pointed out as a highly interesting object for experimental research.

* From the Proceedings of the Royal Society of Edinburgh, February 1850.

† It will appear also, with some slight alterations made by the author, in the Cambridge and Dublin Mathematical Journal, Nov. 1850.—W. T.

To test the phænomenon by experiment without applying excessively great pressure, a very sensitive thermometer would be required, since for ten atmospheres the effect expected is little more than the tenth part of a Fahrenheit degree; and the thermometer employed, if founded on the expansion of a liquid in a glass bulb and tube, must be protected from the pressure of the liquid, which, if acting on it, would produce a deformation, or a least a compression of the glass that would materially affect the indications. For a thermometer of extreme sensibility, mercury does not appear to be a convenient liquid; since, if a very fine tube be employed, there is some uncertainty in the indications on account of the irregularity of capillary action, due probably to superficial impurities, and observable even when the best mercury that can be prepared is made use of; and again, if a very large bulb be employed, the weight of the mercury causes a deformation which will produce a very marked difference in the position of the head of the column in the tube according to the manner in which the glass is supported, and may therefore affect with uncertainty the indications of the instrument. The former objection does not apply to the use of any fluid which perfectly wets the glass; and the last-mentioned source of uncertainty will be much less for any lighter liquid than mercury, of equal or greater expansibility by heat. Now the coefficient of expansion of sulphuric æther at 0° C. being, according to M. I. Pierre*, ·00151, is eight or nine times that of mercury (which is ·000179, according to Regnault), and its density is about the twentieth part of the density of mercury. Hence a thermometer of much higher sensibility may be constructed with æther than with mercury, without experiencing inconvenience from the circumstances which have been alluded to. An æther thermometer was accordingly constructed by Mr. Robert Mansell of Glasgow, for the experiment which I proposed to make. The bulb of this instrument is nearly cylindrical, and is about $3\frac{1}{2}$ inches long and $\frac{3}{8}$ths of an inch in diameter. The tube has a cylindrical bore about $6\frac{1}{2}$ inches long: about $5\frac{1}{2}$ inches of the tube are divided into 220 equal parts. The thermometer is entirely inclosed, and hermetically sealed in a glass tube, which is just large enough to admit it freely †. On comparing the indications of this instru-

* See Dixon on Heat, p. 72.

† Following a suggestion made to me by Professor Forbes of Edinburgh, I have in subsequent experiments with this thermometer, used it with enough of mercury introduced into the tube in which it is hermetically sealed to entirely cover its bulb; as I found that, without this, if the experiment was conducted in a warm room, the indications of the thermometer were frequently deranged by the portion of the water which was left free from ice becoming slightly elevated in temperature.

ment with those of a thermometer of Crichton's with an ivory scale, which has divisions corresponding to degrees Fahrenheit of about $\frac{1}{23}$th of an inch each, I found that the range of the æther thermometer is about 3° Fahrenheit; and that there are about 212 divisions on the tube corresponding to the interval of pressure from 31° to 34°, as nearly as I could discover from such an unsatisfactory standard of reference. This gives $\frac{1}{71}$ of a degree for the mean value of a division. From a rough calibration of the tube which was made, I am convinced that the values of the divisions at no part of the tube differ by more than $\frac{1}{30}$th of this amount from the true mean value; and, taking into account all the sources of uncertainty, I think it probable that each of the divisions on the tube of the æther thermometer corresponds to something between $\frac{1}{68}$ and $\frac{1}{73}$ of a degree Fahrenheit.

With this thermometer in its glass envelope, and with a strong glass cylinder (Œrsted's apparatus for the compression of water), an experiment was made in the following manner:—

The compression vessel was partly filled with pieces of clean ice and water: a glass tube about a foot long and $\frac{1}{10}$th of an inch internal diameter, closed at one end, was inserted with its open end downwards, to indicate the fluid pressure by the compression of the air which it contained; and the æther thermometer was let down and allowed to rest with the lower end of its glass envelope pressing on the bottom of the vessel. A lead ring was let down so as to keep free from ice the water in the compression cylinder round that part of the thermometer tube where readings were expected. More ice was added above; so that both above and below the clear space, which was only about two inches deep, the compression cylinder was full of pieces of ice. Water was then poured in by a tube with a stopcock fitted in the neck of the vessel, till the vessel was full up to the piston, after which the stopcock was shut.

After it was observed that the column of æther in the thermometer stood at about 67°, with reference to the divisions on the tube, a pressure of from 12 to 15 atmospheres was applied, by forcing the piston down with the screw. Immediately the column of æther descended very rapidly, and in a very few minutes it was below 61°. The pressure was then suddenly removed, and immediately the column in the thermometer began to rise rapidly. Several times pressure was again suddenly applied, and again suddenly removed, and the effects upon the thermometer were most marked.

The fact that the freezing-point of water is sensibly lowered by a few atmospheres of pressure was thus established beyond all doubt. After that I attempted, in a more deliberate experiment, to determine as accurately as my means of observation allowed me to do, the actual extent to which the temperature of freezing is affected by determinate applications of pressure.

In the present communication I shall merely mention the results obtained, without entering at all upon the details of the experiment.

I found that a pressure of, as nearly as I have been able to estimate it, 8·1 atmospheres produced a depression measured by $7\frac{1}{2}$ divisions of the tube on the column of æther in the thermometer; and again, a pressure of 16·8 atmospheres produced a thermometric depression of $16\frac{1}{2}$ divisions. Hence the observed lowering of temperature was $\frac{7\frac{1}{2}}{71}$, or ·106° F. in the former case, and $\frac{16\frac{1}{2}}{71}$, or ·232° F. in the latter.

Let us compare these results with theory. According to the conclusions arrived at by my brother in the paper referred to above, the lowering of the freezing-point of water by 8·1 atmospheres of pressure would be 8·1 × ·0135, or ·109° F.; and the lowering of the freezing-point by 16·8 atmospheres would be 16·8 × ·0135, or ·227° F. Hence we have the following highly satisfactory comparison, for the two cases, between the experiment and theory:—

Observed pressures.	Observed depressions of temperatures.	Depressions according to theory, on the hypothesis that the pressures were truly observed.	Differences.
8·1 atmospheres ...	·106° F.	·109° F.	−·003° F.
16·8 atmospheres ...	·232° F.	·227° F.	+·005° F.

It was, I confess, with some surprise, that, after having completed the observations under an impression that they presented great discrepancies from the theoretical expectations, I found the numbers I had noted down indicated in reality an agreement so remarkably close, that I could not but attribute it in some degree to chance, when I reflected on the very rude manner in which the quantitative parts of the experiment (especially the measurement of the pressure, and the evaluation of the division of the æther thermometer) had been conducted.

I hope before long to have a thermometer constructed, which shall be at least three times as sensitive as the æther thermometer I have used hitherto; and I expect with it to be able to perceive the effect of increasing or diminishing the pressure by less than an atmosphere, in lowering or elevating the freezing-point of water.

If a convenient *minimum* thermometer could be constructed, the effects of very great pressures might easily be tested by hermetically sealing the thermometer in a strong glass, or in a metal tube, and putting it into a mixture of ice and water, in a strong metal vessel, in which an enormous pressure might be produced by the forcing-pump of a Bramah's press.

In conclusion, it may be remarked, that the same theory which pointed out the remarkable effect of pressure on the freezing-point of water, now established by experiment, indicates that a corresponding effect may be expected for all liquids which expand in freezing; that a reverse effect, or an elevation of the freezing-point by an increase of pressure, may be expected for all liquids which contract in freezing; and that the extent of the effect to be expected may in every case be deduced from Regnault's observations on vapour (provided that the freezing-point is within the temperature-limits of his observations), if the latent heat of a cubic foot of the liquid, and the alteration of its volume in freezing be known.

XIII. *On a remarkable appearance of Lightning.* *By* J. P. Joule, *F.R.S.*

To the Editors of the Philosophical Magazine and Journal.

Gentlemen,

On the 16th inst., after a very sultry morning, this town was, in common with a large tract of country, visited at 4 o'clock by a thunder-storm accompanied with heavy rain. In the evening of the same day, about 9 o'clock, we had an opportunity of witnessing a most magnificent display of electrical discharges, which continued almost uninterruptedly for the space of one hour, accompanied, however, by only a few drops of rain. I had never before seen lightning of such an extraordinary character. Each discharge appeared to emanate from a mass of clouds in the south-west, and travelled six or ten miles in the direction of the spectator, dividing into half a dozen or more sparks, or zigzag streams of light, in some instances the termination of each of these sparks being, as represented in the adjoining sketch, again subdivided into a number of smaller sparks. I did not observe any of the discharges to strike the ground; and from the interval of time between the appearance of those which crossed the zenith and